AFCRL-65-190

GEOLOGY OF THE NORTH AMERICAN AIR DEFENSE COMBAT OPERATIONS CENTER, CHEYENNE MOUNTAIN AND PERIPHERAL AREA, NEAR COLORADO SPRINGS, EL PASO COUNTY, COLORADO

Steven D. Theodosis and James W. Skehan, S.J.

Trustees of Boston College
Chestnut Hill, Mass. 02167

Contract No. AF 19(628)-1622
Project No. 4600
Task No. 460008

Scientific Report No. 2

March 8, 1965

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

Requests for additional copies by agencies of the Department of Defense, their contractors, or other government agencies should be directed to:

Defense Documentation Center (DDC)
Cameron Station
Alexandria, Virginia 22314

Department of Defense contractors must be established for DDC services or have their "need-to-know" certified by the cognizant military agency of their project or contract.

All other persons and organizations should apply to the:

Clearinghouse for Federal Scientific
and Technical Information (CFSTI)
Sills Building
5285 Port Royal Road
Springfield, Virginia 22151

AI

CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION, CFSTI
INPUT SECTION 410.11

AD615724

LIMITATIONS IN REPRDDUCTION QUALITY OF TECHNICAL ABSTRACT BULLETIN DOCUMENTS, OEFENSE DOCUMENTATION CENTER (OOC)

☐ 1. AVAILABLE ONLY FOR REFERENCE USE AT DDC FIELD SERVICES. COPY IS NOT AVAILABLE FOR PUBLIC SALE.

☒ 2. AVAILABLE COPY WILL NOT PERMIT FULLY LEGIBLE REPROOUCTION. REPROOUCTION WILL BE MADE IF REQUESTED BY USERS OF DDC.

☒ A. COPY IS AVAILABLE FOR PUBLIC SALE.

☐ B. COPY IS NOT AVAILABLE FOR PUBLIC SALE.

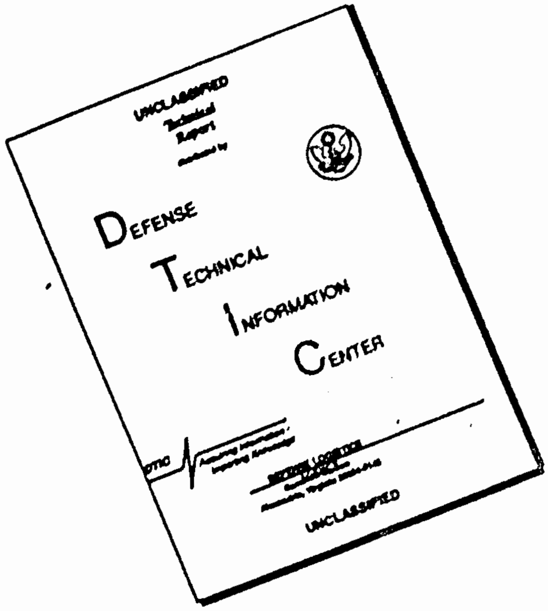
☐ 3. LIMITEO NUMBER OF COPIES CONTAINING COLOR OTHER THAN BLACK AND WHITE ARE AVAILABLE UNTIL STOCK IS EXHAUSTEO. REPRODUCTIONS WILL BE MAOE IN BLACK AND WHITE ONLY.

TSL-121-2/65

DATE PROCESSED: 6-9-65

PROCESSOR: G. Lee

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

AFCRL-65-190

GEOLOGY OF THE NORTH AMERICAN AIR DEFENSE COMBAT OPERATIONS CENTER, CHEYENNE MOUNTAIN AND PERIPHERAL AREA, NEAR COLORADO SPRINGS, EL PASO COUNTY, COLORADO

Steven D. Theodosis and James W. Skehan, S.J.

Trustees of Boston College

Chestnut Hill, Mass. 02167

Contract No. AF 19(628)-1622

Project No. 4600

Task No. 460008

Scientific Report No. 2

8 March 1965

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

Looking north-northwest towards Pikes Peak in the background and Cheyenne Mountain in the middleground. The latter contains the NORAD COC with its North and South Portals, access road, and the edge of Fort Carson in the foreground.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

List of Contributors

In addition to the authors, the following scientists and technical assistants have materially contributed to the research reported on in this document: W.A. Cobban, C.C. Hawley, and C.S. Robinson of the U.S. Geological Survey, Denver, Colorado, Virgil B. Cole, Lydia M. McCarthy, Walter J. Arabasz, Charles N. Legarde, III, Dennis W. O'Leary, Raymond J. Pezzoli, James Keough, James Ashley, and Mary K. Wier. The photographs contained herein were obtained through the cooperation of Colonel Spencer S. Hunn, U.S.A.F., Ent Air Force Base, Colorado.

Publication Previously Produced on the Contract

Skehan, S.J., James W., 1963, Geology of the Basement Complex of Southeastern Nebraska, Northeastern Kansas and Vicinity: Air Force Cambridge Research Laboratory Publication AFCRL-63-173, 57 p.

Abstract

The NORAD Project, a Combat Operations Center (COC), is a hardened underground command installation with communications, electronic-data processing, and other facilities capable of sustaining independent operation for a specified period under a buttoned-up status following an attack which has interrupted outside support.

The COC is located in Cheyenne Mountain which consists almost entirely of granite. The granite within the COC is highly fractured, the fracturing being expressed as joints and shear zones genetically related to the frontal fault zone, the Ute Pass Fault.

The Ute Pass Fault forms the major boundary plane along the eastern side of an extensive granitic block which has been vertically uplifted in excess of 20,000 feet and partially thrust over a 7000-8000 foot thickness of sedimentary beds east of this boundary. The strata have been deformed by compressive shear stresses related to the vertically directed principal stresses associated with Ute Pass Fault geology.

The investigation of the area was undertaken to: (1) establish the distribution of major geologic features which could have an important bearing on interpretation of deep crustal resistivity data, and (2) to locate a drill hole for use in deep strata communication testing.

Location

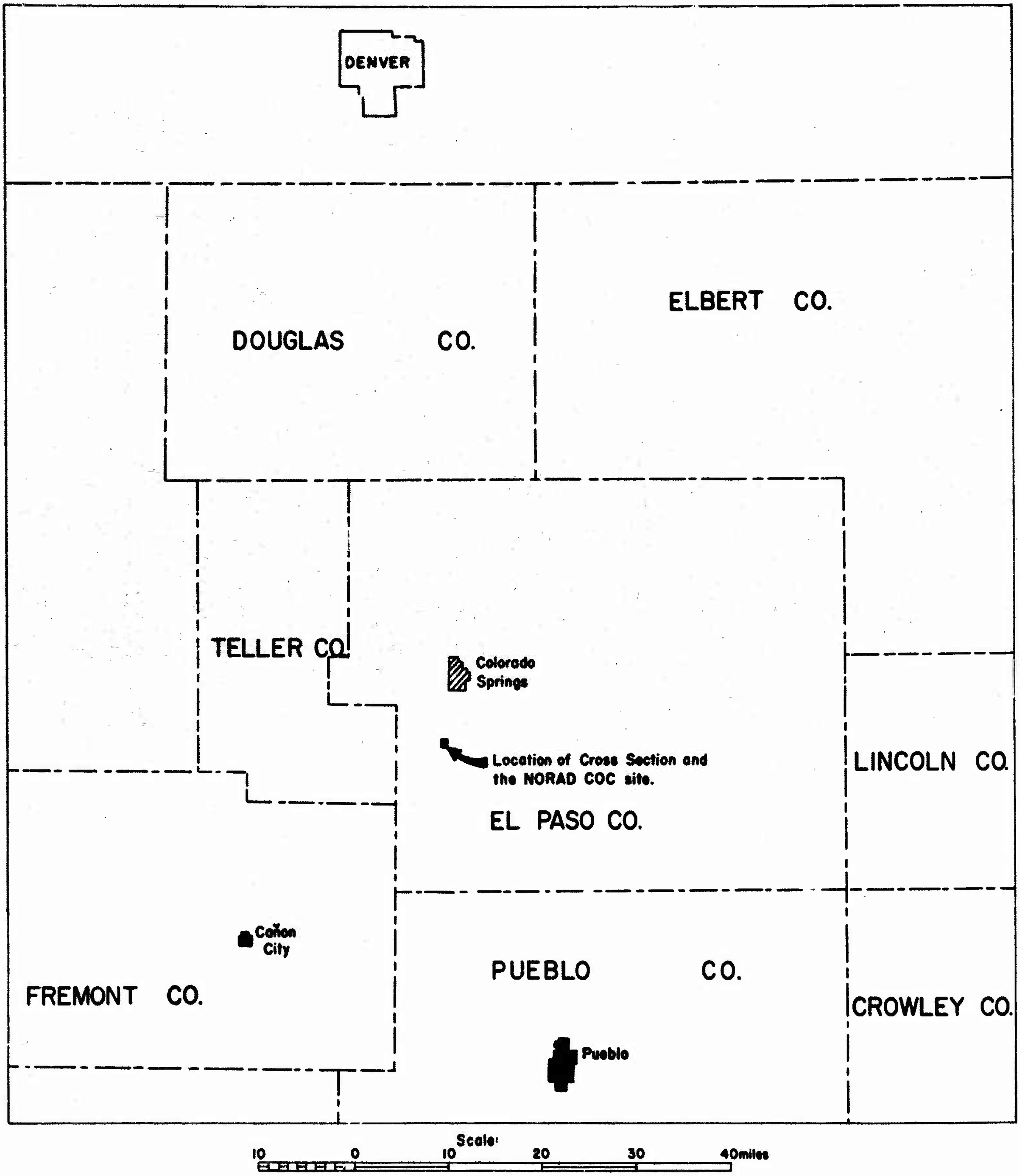
The area of principal interest encompasses an area 35 miles in radius centered on the Cheyenne Mountain North American Air Defense Combat Operations Center (COC), which is located five miles south of Colorado Springs, and two miles west of Fort Carson (Plate 1), El Paso County, Colorado.

The Colorado Springs - Cheyenne Mountain area is within the geological province of the Southern Rocky Mountains. Cheyenne Mountain is just south of the Rampart Range, which is a southern extension of the Colorado Front Range.

West of the Ute Pass Fault which forms the eastern topographic boundary of Cheyenne Mountain, elevations rise abruptly to 9300 feet, with the general area to the west having an average elevation of 8500 feet. Elevations of the Great Plains several miles to the east of the Rampart Range approximate 6000 feet, and rise abruptly to 7000 feet at the mountain front.

Purpose of the Study

Investigation of the geology of the Colorado Springs and



MAP SHOWING LOCATION OF CROSS SECTION AND NORAD COC SITE

PLATE I

peripheral area was undertaken with a two-fold purpose: (1) to establish the distribution of major geologic features important in interpreting deep crustal resistivity data, and (2) to locate a drill hole for use in deep strata communication testing.

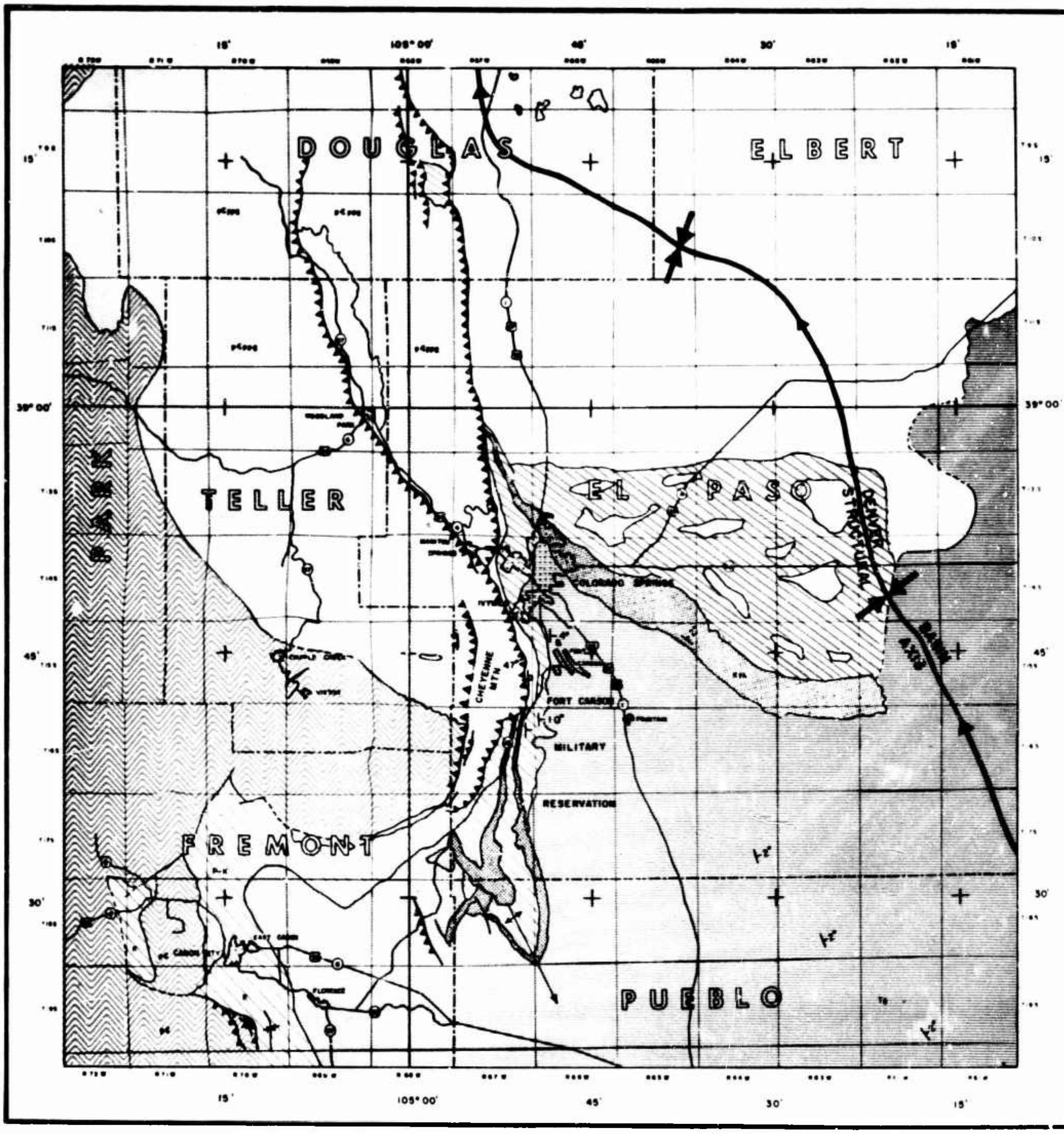
Scope of Investigation

Published and unpublished geological information was compiled and analyzed. Detailed geologic maps (scale 1 inch to 4000 feet), not included in this report, were prepared to facilitate a comprehensive understanding of the internal geologic structure of Cheyenne Mountain and the eastern frontal fault zone of sedimentary rocks (Plate 2) comprising the Great Plains.

Data from wells drilled in the area were embodied in the study, as was seismic geophysical information obtained from private sources.

Field work to obtain detailed geologic data necessary for the construction of a cross-section (Plate 3) was conducted in June, July, and August of 1964. Surfac studies included the collection and identification of fossils which facilitated structural interpretation of the frontal zone of sedimentary rocks.

Well data, surface investigations and all other sources of information were combined into regional and local geologic



LEGEND

MAJOR EARTH DISPLACEMENTS

ANTICLINE

SYNCLINE

BASIN AXIS

HIGHWAYS

PLATE 2

GROSS TECTONICS AND DISTRIBUTION OF MAJOR ROCK TYPES OF COLORADO SPRINGS-CHEYENNE MTN. AREA COLORADO

LITHOLOGY

CONGLOMERATES, SANDSTONES, SHALES AND CLAYS OF VARIABLE THICKNESS UP TO 4000ft PERMEABLE WITH PERCHED WATER TABLES

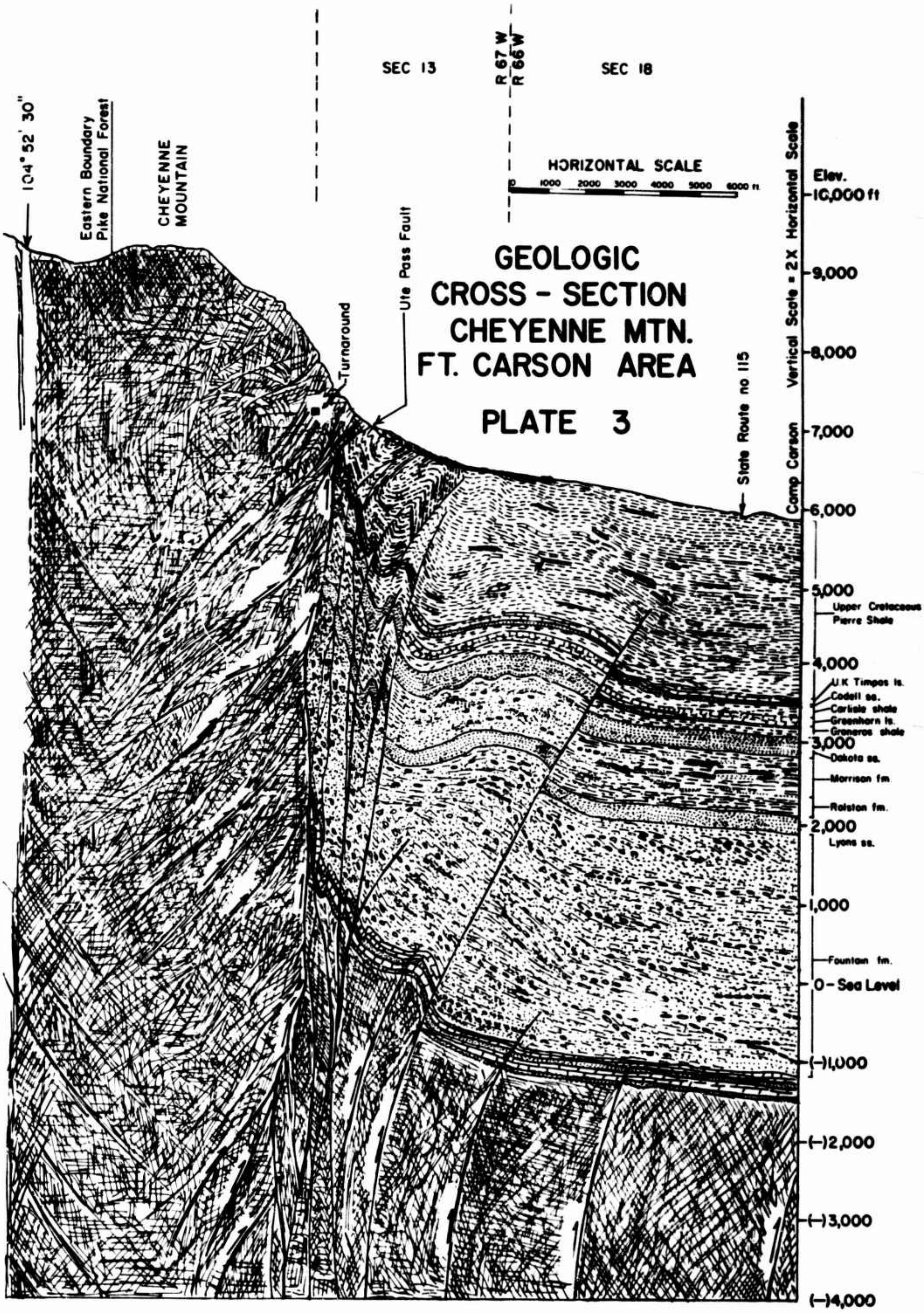
VARIABLE LITHOLOGY AND PERMEABILITY. SANDSTONES, SILTSTONE AND CLAYS. LIMESTONES LIMITED TO LOWER PART

PERMEABLE SANDSTONE STRATA GENERALLY SATURATED AND ACTING AS WATER RESERVOIRS

IMPERMEABLE SHALE STRATA GENERALLY NON-WATER BEARING WITH OCCASIONAL LENSES OF SILTY SANDSTONE

PIKES PEAK GRANITIC ROCKS - WATER CONTAINED ALONG JOINTS, FRACTURES AND FISSURE ZONES

METAMORPHIC ROCKS OF VARIOUS ORIGIN AND TEXTURE META IGNEOUS AND META-SEDIMENTARY AND VARIABLE PERMEABILITY



GEOLOGIC
CROSS - SECTION
CHEYENNE MTN.
FT. CARSON AREA
PLATE 3
SEC 13
SEC 18
R 67 W
R 66 W
104° 52' 30"
Eastern Boundary
Pike National Forest
CHEYENNE
MOUNTAIN
Turnaround
Ute Pass Fault
State Route no 115
Camp Carson
HORIZONTAL SCALE
0
1000
2000
3000
4000
5000
6000 ft
Vertical Scale = 2X Horizontal Scale
Elev.
10,000 ft
9,000
8,000
7,000
6,000
5,000
Upper Cretaceous
Pierre Shale
4,000
U.K Timpas ls.
Codell ss.
Carlisle shale
Greenhorn ls.
Graneros shale
3,000
Dakota ss.
Morrison fm.
Ralston fm.
2,000
Lyons ss.
1,000
Fountain fm.
0 - Sea Level
(-)1,000
(-)2,000
(-)3,000
(-)4,000

maps and cross-sections to establish the distribution of major geologic features and to assist in locating a drill hole for use in deep strata communication studies.

Geology of the Cheyenne Mountain Granite

Cheyenne Mountain, in which the North American Air Defense COC is emplaced, consists almost entirely of one major rock type, granite.

Data from these new studies and from previous studies by the authors and others indicate that the granite of Cheyenne Mountain was emplaced as a molten mass by intrusion into older rocks at depths of several miles below sea level approximately one billion years ago. As the mass cooled, it slowly solidified into a relatively homogeneous, coarse-grained, crystalline rock having a mineral composition characteristic of granite. Technically, the term granite is reserved for quartz-bearing granular igneous rocks that have potassium feldspars as the chief mineral.

During the cooling stages of solidification of the granite, a decrease in volume ensued which produced tension fractures in the rock. Such fractures, in which no visible movement took place parallel to the plane of the fracture, are called "joints". The Cheyenne Mountain granite is characterized by many such joints spaced several feet apart in oblique,

vertical and horizontal attitudes. The presence of numerous joints is suggested diagrammatically in Plate 3 and also in Plate 4.

Once solidified, the granite mass was subjected to vertically directed earth forces which displaced the granite upwards throughout geological time until the granitic mass was eroded and exposed to the atmosphere several miles above sea level.

The internal reaction of the granite to the varied dynamic stresses that differentially uplifted the rock masses to their present elevation produced countless fractures and ruptures within the granite along which differential movements took place. Such displacements, where great in magnitude, are known as shear zones and faults. [illegible] associated with such major disruptive movements are a series of differential but systematically related smaller displacements called shear fractures (Plate 3).

As illustrated on the maps showing geologic structures and distribution of rock types (Plate 2) and the cross-sections ([illegible]), a series of major shear zones are present in [illegible] Mountain. Maximum fracturing of the granite has taken place in the blocks between the shear zones and is most intense adjacent to these zones. The development of shear zones in the granite is related to the main frontal fault zone, the Ute Pass Fault, which structurally separates the

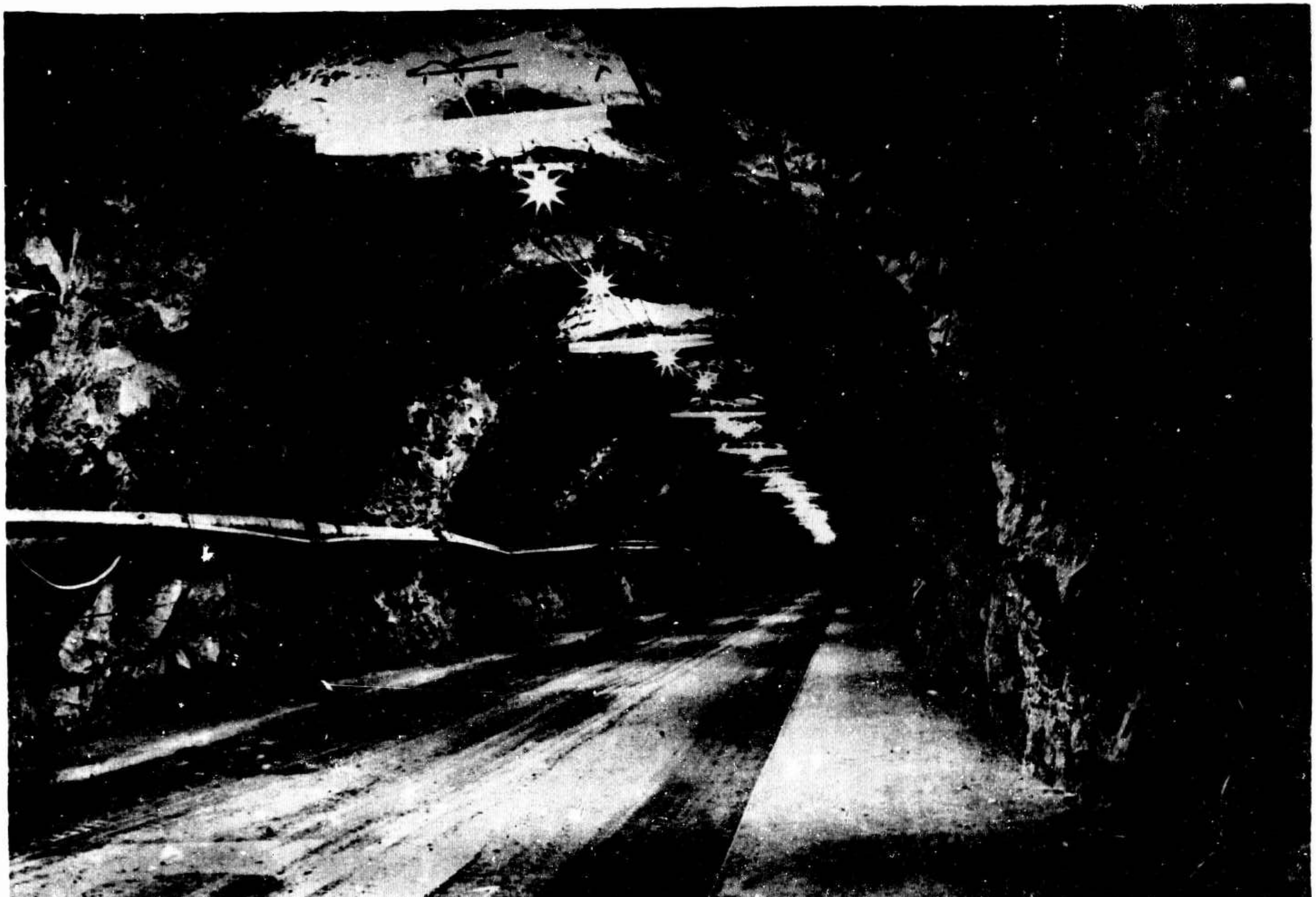
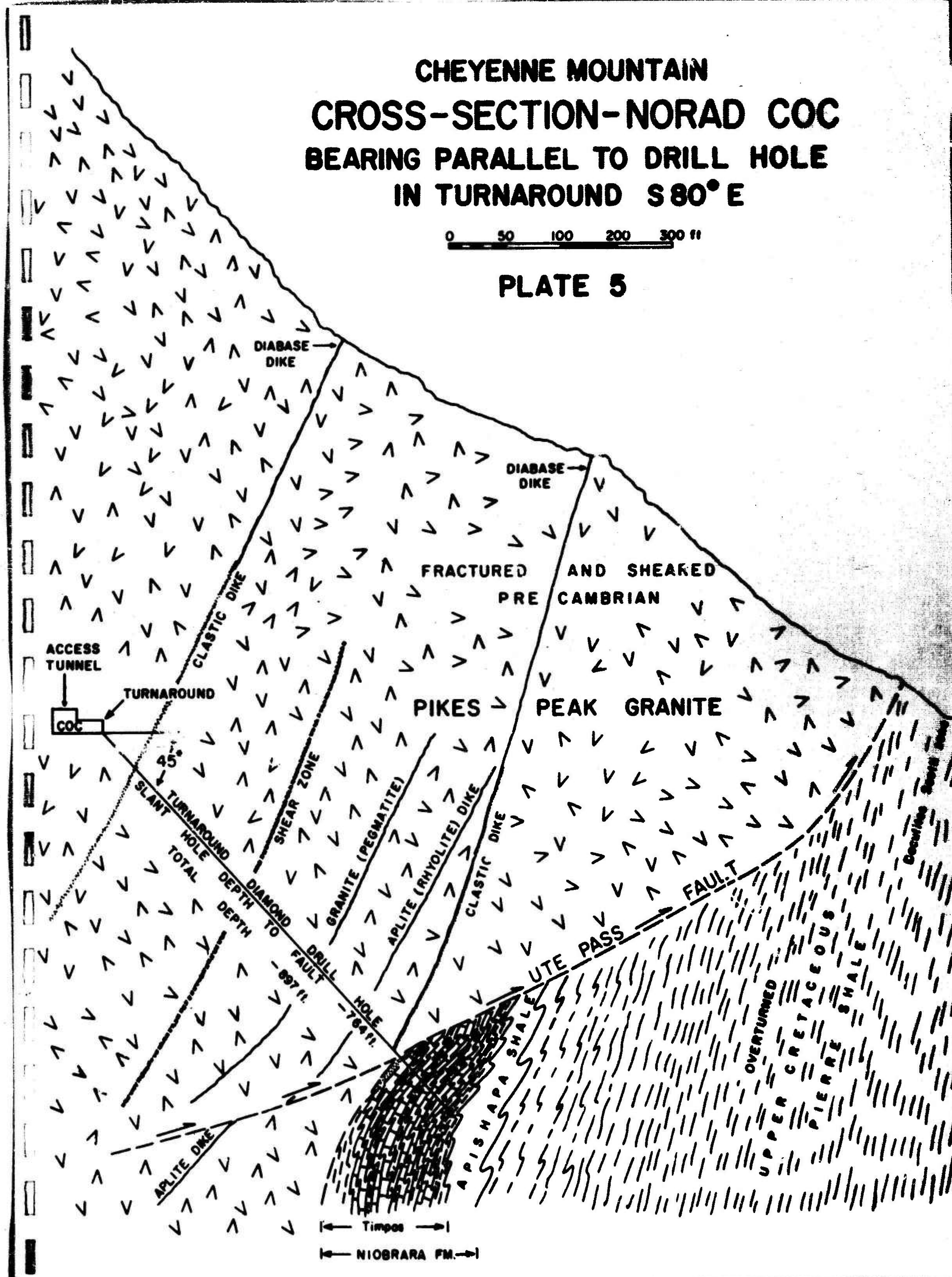


Plate 4. Interior view of the North Access Tunnel showing the closely jointed nature of the granite.

CHEYENNE MOUNTAIN

CROSS-SECTION-NORAD COC

BEARING PARALLEL TO DRILL HOLE IN TURNAROUND S 80° E



granites of the Rampart Range - Cheyenne Mountain massif from the younger sedimentary rocks to the east.

Shear fractures and joints adjacent to the frontal fault zones are complex, intense, and varied. Where the granite is coarse-grained, alteration of the minerals along the joints is extensive near major and subsidiary shear zones. Such alteration is seen just north of the NORAD COC along the Cheyenne Mountain road on the approach to the Will Rogers Memorial. In such zones the minerals are considerably altered to softer secondary hydrated by-products.

Although normal, fresh, unaltered granite is essentially impermeable to water and has high electrical resistivity, internal breakage and fracturing provides permeable zones through which water passes readily. Surface waters from snow and rain percolate through the fractures and dissolve small amounts of carbon dioxide forming carbonic acid (HCO_3). Such acids attack and chemically alter the minerals in the granites. These fractured zones containing water with dissolved salts give high conductivity values. Therefore, high resistivity in the granite of this area can be generally correlated with less highly fractured zones, whereas areas of lower resistivity may be correlated with water-saturated fracture zones.

During the complex billion-year history of the Cheyenne

Mountain granitic mass, younger intrusive rocks of varied composition were emplaced in localized fissure zones in the granite.

Also in the course of the geologic history of the granite, some open fractures were exposed to surface erosion thus permitting the fissures to be filled with loose, unconsolidated sedimentary material which was later buried and compressed into hard rock referred to as "clastic dikes". Such "clastic dikes" have been observed on the surface near the frontal fault zone, and have been encountered in several areas in drill holes (Table 1 and Plate 5).

The granite of Cheyenne Mountain is called the "Pikes Peak granite" because of its great areal distribution (Plate 2) which includes Pikes Peak (el. 14,110 feet) near Colorado Springs (Frontispiece).

Sedimentary Rocks of the Frontal Zone Plains

In the course of the last 500 million year history of the Cheyenne Mountain area, nearly 10,000 feet of sedimentary rocks were deposited along the eastern flank of the Rampart Range in the present Great Plains. Adjacent to, and several miles to the east of the portal entrances to the NORAD COC, there are preserved nearly 7500 feet of sedimentary strata which vary in composition and structural attitude (Plates 2 and 3).

Table 1

Depth in Feet	Description of core from drill hole taken at Turnaround, NORAD COC Site, Cheyenne Mountain, Colorado Springs, Colorado.
1 - 521	Granite; chiefly coarse-grained, grey to pink, containing biotite mica, plagioclase and pink potash feldspar and quartz; fractured along joint planes; chiefly undecomposed but slightly to highly decomposed clay minerals in some zones especially along fractures; calcite-filled fractures in some parts of the core.
521 - 554	Highly fractured and altered granite in a major zone of fracturing.
554 - 685	Granite; same as in interval 1 - 521'.
685 - 754	Highly fractured granite in a shear zone subsidiary to the main Ute Pass Fault zone.
754 - 761	Altered and brecciated basalt dike.
761 - 776	Major fault zone, the Ute Pass Fault, with fault gouge. The gouge consists of calcareous to non-calcareous shaly mudstone.
776 - 784.5	Brecciated white quartz sandstone of Cretaceous age, and quartz sandstone.
784.5 - 793	Micaceous calcareous mudstone gouge zone in a subsidiary shear zone within the Ute Pass Fault zone.
793 - 803.3	Calcareous silty shales.
803.3 - 818	Light grey limestone with black shale layers in nearly vertical attitude.
818 - 829	Calcareous black shale in which are dense, dark-grey limestone layers one of which contains Inoceramus fossils (a key guide fossil as to age of rock) which suggests that it is part of the Timpas limestone.
829 - 897	Alternating calcareous dark shale and limestone.
897	Coring discontinued at this depth, probably in the Lower Fort Hays limestone.

The sedimentary strata, adjacent to the eastern topographic break in slope of the Cheyenne Mountain Front, are complexly folded into west-dipping overturned strata (Plates 3 and 5), which return to normal east-dipping attitudes within a mile east of the mountain front (Plate 3). At Fort Carson, two miles east of the mountain front, strata dip to the east at values of three to four degrees in the direction of the regional synclinal axis formed by the Denver Basin structural axis.

The distribution of the chief sedimentary rock units that make up the surface materials exposed in the Colorado Springs - Cheyenne Mountain region are shown on Plate 2. Also shown on Plate 2, is the areal distribution of the older metamorphic rocks and the Pikes Peak granite.

Gross regional structures and the structural outline of the major fault zone along which earth movements of major magnitude have taken place are shown on Plate 2. It is along such faults that older rocks have been shifted upward in vertical distances exceeding 20,000 feet. Older rocks of the mountain core commonly have been shoved in an easterly direction over younger strata (Plate 5). The presence of a steep eastern mountain front along the whole Southern Rocky Mountains is merely a visible expression of the fact that older rocks have moved upward and eastward along major zones of ancient earthquake activity.

East of the fault zones, the layers of rock which make up the region consist of a variety of rock types having a varied structural expression.

In the Cheyenne Mountain area, the upper 2500 feet of strata (Plate 3) consist of interbedded shaly, silty, and sandy layers with some thin limestone beds.

This sequence of strata is characteristically impermeable to water, and is relatively very dry. However, joints are present in the sequence since all consolidated rocks near the surface behave as brittle substances and have ruptured when subjected to tensional forces. Surface waters percolate into the joint fractures and commonly saturate these zones with water. This phenomenon is local in extent and the surface distribution of water-saturated zones is difficult to predict.

In the vicinity of Fort Carson, at an average depth of 2500-2850 feet, a 350 foot sequence of limestone, sandstone, siltstone, and shale is present. The limestones break in characteristic patterns, and the silty sandstones are sufficiently permeable to be water-saturated, especially near the mountain front. A 200 foot unit of sandstone below this zone, the Dakota sandstone, however, acts as the main water-bearing layer at this depth.

The Dakota sandstone is calculated to be present at a depth of 3900-4100 feet two miles east of the NORAD COC, but

rises to within 1000 feet of the surface (Plate 3) near the Ute Pass Fault. It is in the vicinity of the fractured rocks of the Ute Pass Fault that the Dakota sandstone is recharged with surface waters.

Below the Dakota sandstone, a 700-800 foot series of layers consists of interbedded claystones, mudstones, lenses of sandstone, and limestone. These rocks are only moderately permeable as compared to the more permeable sandstone layers above and below this interval.

The sandstone unit below the rocks just mentioned (Plate 3), approximately 200 feet thick, called the Lyons sandstone, is commonly very permeable and serves as an excellent water reservoir. Like the Dakota sandstone, it is recharged with water in the up-dip fracture zone near the mountain front. Its relative position in depth varies in terms of its structural position east of the mountain front (Plate 3).

Below the Lyons sandstone, at an approximate depth of 4100-7200 feet, there is a 3100 foot sequence of irregularly bedded sandstones and conglomerates containing lenses of shale, mudstone, and siltstone. Conglomeratic pebble-zones commonly fill ancient stream channels and are usually saturated with water.

Below this sequence and immediately above the "basement rocks" is a 250 foot interval of limestones and sandstones

(Plate 3) which contains a basal sandstone unit of variable thickness, but locally reaches a thickness of 100 feet. Normally saturated with water, this basal sandstone unit may serve as a source of water to supply and saturate the upper fractured zones of the granitic and metamorphic rocks that comprise the "basement rocks" at depths ranging from 5000 feet adjacent to the mountain front, to depths exceeding 8000 feet east of Fort Carson (Plate 3).

As no deep wells have been drilled into the "basement rocks" anywhere near the vicinity of the Cheyenne Mountain area, no reservoir characteristics, pressure gradients, or specific hydraulic values are known. However, textural characteristics of the rock formations are known by projection, and valid inferences as presented above, can be made from such general data to assist the geophysicist and engineer in evaluating resistivity measurements made in the sedimentary sequence overlying the basement rocks.

Selection of the Drill Hole Site

The decision to select and drill the site for testing underground radio communications in the NORAD COC Turnaround was based on several factors as follows:

(1) Maximum security and non-interference from other personnel.

(2) Position and angle of drill hole to most approximately parallel the eastern topographic slope of Cheyenne Mountain (Plate 5).

(3) Maximum competency, high resistivity, and maximum stability of rock-type to permit drilling of hole in terms of minimum time and expense.

(4) Availability of sufficient air pressure and quantity of water to permit continued uninterrupted drilling of the hole at normal rates.

(5) Accessibility of area in NORAD COC which would not interfere with other operations.

(6) Proximity to "ties" with surface antennas within the NORAD COC.

Drilling of the Test Hole

Boyles Brothers Drilling Company of Denver, commenced drilling the test hole on 8 September 1964 and completed drilling of the hole on 17 October 1964 while under contract to Grafe-Wallace-Foster, one of the principal contractors at the NORAD COC.

The hole was drilled within the NORAD COC Turnaround. It is located seven feet south of the center line, and seven feet west of the east face of the Turnaround. The hole is slanted 45° and was drilled in a direction bearing approximately N 100° E. The upper 20 feet of the hole was cemented,

re-drilled, and cased with "B" steel tubing to permit facility of entry into the hole. The hole is 2-3/8 inches in outside diameter. It was drilled to a slant-hole depth of 897 feet. Because of fracturing encountered in the granite during the drilling, water seepage along the fractures has filled the hole with water to within 20 feet of the entrance to the hole. The hole, however, was free of obstructions to permit insertion of electronic equipment to a slant-hole depth of 762 feet without having to insert plastic pipe or to cement the hole.

Rock Description Log of the Core from the Hole

The hole was drilled in relatively solid, although fractured granite to a slant-hole depth of 764 feet, at which depth the Ute Pass Fault zone was encountered (Plate 5). The lower 133 feet of the hole encountered shales, sandstones, and limestones of Upper Cretaceous age (Plate 3). As the shales contain bentonitic clays which absorb water and swell to obstruct the hole, the lower part of the hole was abandoned since it does not readily lend itself to insertion of electronic equipment without being cemented and re-drilled at considerable expense.

An abbreviated log describing the lithology of the rocks encountered in drilling, and the structures contained therein, make up Table 1. A fuller description of the detailed lithologies of the core is presented in Appendix 1.

Recommendations for Further Drilling

Having ascertained by drilling, the near-surface structural dip of the Ute Pass Fault zone (Plates 3 and 5), and being able to predict with some assurance the intense fracturing of rocks associated with the faulting, it is predictable that additional slant-holes can be drilled within the NORAD COC that will facilitate insertion of longer lengths of electronic equipment for future testing.

If it is desirable to have a hole paralleling the eastern surface slope of Cheyenne Mountain, such drilling should be done at the westernmost extremities of the A or B corridors within the NORAD complex. The drilling should again be directed towards the east.

However, since the water table above the NORAD COC has been lowered by the excavations, a non-water saturated hole could be obtained by slant drilling upwards in a westward direction from within the COC site at a place selected on the basis of the length of the hole desired, or what would amount to the same thing is to drill a hole from the surface on an eastward slant downward to the COC site.

Conclusions

The granitic rock of the Cheyenne Mountain COC is an extremely fractured and jointed granite (Plate 4). The

fractures, shear zones, and joints are related in origin to the frontal Ute Pass Fault zone. Specific zones of very intensive fracturing are localized. This fact is evidenced by delays of construction necessitated by rock-bolting and shoring up of the rock roof to permit them to withstand tremendous shocks without having joint blocks spall by resulting tensional forces created by such a shock. Although the rock itself is not well suited to withstand severe tensional shocks, the internally housed steel structures and drill holes should be sufficiently stable to permit intended functioning under a buttoned-up status following an attack under which outside support has been interrupted.

Appendix I

NORAD COC Turnaround Diamond Drill Hole

Description of wire-line diamond core taken from 45° slant hole drilled in the Turnaround area of the NORAD COC. Hole is directed approximately 10° south of east bearing and was drilled to the east. Bx hole (2-3/8 in., outside diameter) was drilled 8 September - 17 October 1964; it is located 7 feet south of the center line of the Turnaround, and 7 feet west of the east face of the Turnaround. The upper 20 feet of the hole was cemented, re-drilled, and cased with "B" steel tubing to permit facility of entry into the hole. The hole is 897 feet in slant-hole depth; 762 feet were drilled in granite and the remaining 135 feet are in fault gouge of the Ute Pass Fault, and shales, sandstones, and limestones of Upper Cretaceous age. Megascopic examination by means of 10X hand-lens and this description was made by Dr. Steven D. Theodosis.

Inclined distance in feet	Description of Core
	NOTE: From 1-762' the rock is pinkish-grey granite and the core is competent unless otherwise stated.
1 - 8	Coarse-grained, 10-15% biotite mica, 30-35% grey plagioclase feldspar, 25-30% large irregular crystals of pink potash feldspar, 25% light grey quartz.
8 - 9	Fractured and slightly altered.
9 - 13.5	Normal, medium to coarse-grained.
13.5 - 14	Slightly altered along fractures.
14 - 18.5	Coarse-grained, undecomposed.
18.5 - 19.5	Kaolinized.
19.5 - 21	Slightly fractured; biotite granite.
21 - 30	Unaltered.
30 - 41	Coarse to medium-grained.

41 - 61.5		Slightly fractured; relatively fresh and unaltered quartz-ortho-clase-plagioclase granite.
61.5		Chlorite prominent along joint fracture.
61.5 - 64		Coarse-grained with chlorite and biotite; slight kaolinization of feldspars.
64 - 70.5		Relatively unaltered and undecomposed; slight chlorite alteration in micas along fracture at 65'.
70.5 - 76		Coarse-grained; micas altered to chlorite along fractures.
76 - 82.5		Red orthoclase predominating.
82.5 - 84		Highly fractured, granulated; highly leached along fracture zone.
84 - 84.5	Clastic Dike	Material firm, highly cemented; may be mylonitized zone; grains appear to be rounded and unfractured, and may represent fissure-fill material.
84.5 - 86		Slightly kaolinized feldspars; probably represents leaching along fissure-type joint system.
86 - 102		Unaltered; some quartz, orthoclase, biotite, and plagioclase.
102 - 104		Coarse-grained, gneissoid; fractured, relatively undecomposed.
104 - 110		Undecomposed, medium to coarse-grained.
110 - 112		Slightly fractured.
112 - 115		Fractured, iron-stained; more highly micaceous granite with slightly kaolinized feldspars.
115 - 120		Micaceous; slight gneissoid texture and mica schlieren; fractures re-cemented.

120 - 151.5	Porphyritic, coarse-grained; prominent orthoclase crystals up to 2" in diameter.
151.5 - 154	Porphyritic; microcline crystals in mica and quartz matrix; fractures parallel to core; sealed and slightly calcareous. Core breaks easily along fracture planes.
154 - 160	Porphyritic with prominent microcline.
160 - 162.5	Relatively unaltered and fractured porphyry; prominent calcite vein parallel to core, structurally weak along fractured zone.
162.5 - 169	Porphyritic; dark grey at 168.5 where mica is more abundant.
169 - 174	35% micas, 40% microcline, 15% quartz, and 10% plagioclase; fractured oblique to core which is otherwise competent.
174 - 184	Coarse-grained to porphyritic with abundant quartz, mica, and plagioclase associated with orthoclase.
184 - 195	Reddish; prominent microcline crystals; sealed fractures are calcitic; core is dense.
195 - 198	Reddish to pinkish-grey; relatively unaltered; shear fractures oblique to core.
198 - 233	Biotite, hornblende, quartz, orthoclase, and plagioclase in varying degrees of admixture; variable spacing of sealed oblique fractures; relatively unaltered.
233 - 237	As above; fractures slightly kaolinized.
237 - 255	Prominent fractures in 1' to 4" intervals along mica-rich planes.
255 - 255.5	Kaolinized; obliquely fractured; calcite veinlets fill fractures.

255.5 - 261	Minor fractures.
261 - 264	Typical reddish Pikes Peak microcline granite.
264 - 304	Homogeneous and competent with occasional oblique calcite-filled fractures at 2' intervals.
304 - 304.5	Fine-grained to aplitic, calcite-filled fractures; aplite probably post-Pikes Peak granite. Hydrothermal alteration associated with aplite intrusion affects the adjacent, normal kaolinized granite. Core appears to be approaching fracture zone.
304.5 - 306	Shear planes hydrothermally altered.
306 - 312	Porphyritic with abundant pink orthoclase; grades downward into normal biotite granite containing a minimum of fractures.
312 - 318.5	Feldspars kaolinized; fractured at 313'.
318.5 - 319	As above. Oblique calcite-filled fractures less than 1 mm. wide.
319 - 321.5	Very coarsely crystalline porphyritic microcline granite. Chloritized micas along fracture zones.
321.5 - 335	Orthoclase granite. Sealed shear fractures at 331'; some accessory pyrite; calcite-filled fracture at 333' of width less than 1 mm.
335 - 335.5	Fractured obliquely to core with calcite-vein fill.
335.5 - 340	Grades into more coarse-grained, light-colored granite.
340 - 341	As above. Core bevels irregularly on outer surface because of irregular cutting along sealed fractures.

341 - 347	Orthoclase-microcline granite; sealed fractures at 346'.
347 - 347.5	Microcline granite; kaolinized feldspar and chloritized micas.
347.5 - 349	Microcline granite.
349 - 353	Porphyry; conspicuous microcline granite in lower foot.
353 - 358	Fractured zone. Granite has gneissoid appearance; kaolinized feldspar; and chloritized micas. Core fractured at 1-3" intervals.
358 - 364	Even, regular core, slightly undulatory along edges where core bit bevels zones containing more micas.
364 - 366	Microcline-orthoclase granite; fractured irregularly to core direction with feldspars kaolinized adjacent to fractures which contain calcite.
366 - 375	Undulatory edges; few calcite-filled seams.
375 - 379	Mylonitized to brecciated; shear zone; kaolinized and chloritized.
379 - 405	Calcite-filled fracture at 391.5 and 402; contains hairline fractures parallel to core.
405 - 409	Fractured; epidotized and chloritized zone.
409 - 430	Coarse-grained, microcline porphyry: microcline zones alternating with zones of black mica and hornblende; fracturing is minor and associated with chloritization of dark minerals at 405-410.
430 - 434	Similar to above; cored along an east-west fracture zone paralleling direction of core. Fractures are calcite filled; feldspars kaolinized; calcite and epidote at 430.3.

433 - 444	As above. At 438.3 a 3" band of black mica; alternating fine-grained and coarse-grained core causes undulatory core cutting; fracture with slight alterations of minerals at 439.5; minor fractures paralleling core at 440'.
444 - 463	Coarse-grained microcline granite with irregular distribution of black biotite mica. Core is undulatory.
463 - 463.3	Black biotitic zone.
463.3 - 471.5	Similar to previous three intervals.
471.5 - 474.5	Coarse-grained, porphyritic microcline granite; fracturing in upper foot with thin calcite-vein fillings.
474.5 - 476	Mylonitized microcline granite; zone displays gneissoid texture and contains abundant epidote, calcite and more than average pyrite; micas are chloritized and feldspars kaolinized.
476 - 477	Microcline granite less altered than previous fracture zone.
477 - 484	Normal microcline granite; sealed oblique-fractures contain chloritized micas at 6" to 1' intervals.
484 - 487	Fracture; moderate alteration of minerals; core breaks easily at intervals of every couple of inches.
487 - 490	Gneissoid; has appearance of rocks in which shear-zone fracturing is lessening away from mylonite zone.
490 - 497	Relatively unaltered microcline granite; several oblique fractures at 492-494.
497 - 498	Irregularly fractured microcline granite.
498 - 512	Reddish microcline granite; 6" fracture breaks at 502, 505, and 512; latter contains epidote and appears mylonitized.

512 - 521	Gneissoid; core breaks irregularly and more frequently at lower interval; approaching a major fracture zone; similar to previous 30' interval.
521 - 554	Reddish, coarse-grained; core is badly broken and fractured, particularly at interval 522-539; kaolinized and chloritized.
554 - 559.5	Reddish pegmatite porphyry; fine-grained to aplitic at the edge of the core-zone interval and coarse-grained in a 6" interval at the center; coarsest at 558.
559.5 - 603	Reddish, coarse-grained microcline porphyry; fractured chips at intervals: 572, 575.8, 577.5, 580, 585, 593, and 594; hydrothermally altered zone at 595.5; relatively competent; general fracture pattern exists parallel to mica planes.
603 - 612	Reddish microcline granite with irregular fractures.
612 - 632.5	Coarse granite porphyry; irregularly fractured core with fracture spacings at 2-6" intervals.
632.5 - 634	Reddish, medium-grained microcline granite.
634 - 651	Reddish, gneissoid microcline granite irregularly fractured; regular ½" fracturing in three intervals perpendicular to core at 637 and 645.5.
651 - 652	Fractures oblique to core along sheared mica planes; zone is mylonitized; micas partially altered to chlorite; some epidote.
652 - 673.5	Reddish, coarse-grained to porphyritic microcline granite; core obliquely fractured at irregular ½-3" intervals; micas altered to chlorite along fractures.

673.5 - 674.8	Rhyolite Dike	Purplish-brown porphyry cutting across coarse-grained, hydrothermally altered granite.
674.8 - 678.5		Microcline granite hydrothermally altered and mylonitized; chloritized micas; alteration associated with late Precambrian rhyolite emplacement.
678.5 679.7	Rhyolite Dike	Irregularly emplaced rhyolite dike cutting across microcline granite which is hydrothermally altered because of rhyolite emplacement; prominent chloritization of micas.
679.7 - 685		Reddish microcline granite; hydrothermal alteration decreases away from rhyolite zone; irregularly fractured across greissen-like mica zones; thin veinlets of rhyolite along fractures.
685 - 733		Reddish microcline granite; intensity of fractures increases with depth at ½-2" breaks which are concentrated along schlieren-like chloritized mica planes; relatively unaltered feldspar.
733 - 754		Very highly fractured; irregularly shaped chips of sizes varying from 1/8-2" in diameter; represents a subsidiary movement of the granite adjacent to the main frontal fault zone.
754 - 761	Basalt (altered dike)	Precambrian diabase dike that is post Pikes Peak granite; hydrothermally altered to a chloritic mass; brecciated to mylonitized by Laramide faulting; similar to the chloritized basalt dike cropping out east of the North Portal entrance at the exposure of the Ute Pass Fault.

761 - 762		Altered granite, pyritized adjacent to basalt dike; micas are almost completely chloritized and are associated with secondary pyrite.
762 - 764	Clastic dike	A lithologically complex Precambrian clastic dike whose mineralogy is diversified; micas chloritized; quartzose matrix shows secondary development of pyrite throughout the core; association is similar to exposures at North Portal.
764 - 772	Fault Gouge	Ute Pass Fault; fault gouge is calcareous to non-calcareous, shaly mudstone containing multiple internal shear planes; this is the major frontal fault zone; shows shallow thrust component; gouge has secondary develepement of pyrite.
772 - 776	Fault Gouge	Distorted Cretaceous black shales; contain boudinage structures; secondary development of pyrite.
776 - 777	Quartzose Sandstone	The previous zone grades downward in the last 1' interval to a brecciated white sandstone; this is not a Precambrian clastic dike commonly associated with major shear zones. It is an Upper Cretaceous sandstone containing secondary pyrite; lithologically like the Codell sandstone which lies below the Timpas limestone. This indicates an overturned relationship based on the dips observed in the core, and on stratigraphic relations to the limestones that follow.
777 - 784.5	Sandstone	Similar to above but better sorted and containing animal burrowings; Codell sandstone type.
784.5 - 793	Fault Gouge	Non-homogeneous, calcareous mudstone gouge zone which possesses multiple shear planes; mudstone gouge is micaceous, with secondary pyrite; this is a subsidiary, but related, shear zone within the Ute Pass Fault zone. The interval 776-785 is a smaller slice of Cretaceous rocks caught within a larger fault zone.

793 - 803.3		Silty shales; carbonaceous to calcareous siltstones and containing secondary pyrite; shales are deformed adjacent to the fault zone; secondary calcite in fractures.
803.3 - 818	Limestone	A light-grey limestone with black shale intervals in 1-4" increments: 804.5, 807.5, 809, 813.5, and at 816.5 intervals. N.B. This limestone resembles the units of the Ft. Hays or Timpas limestone. Structural attitudes approximate a vertical dip. This is in conformable stratigraphic relationship with the overturned Codell sandstone described in the interval 776-784.5. This is a zone of the Timpas limestone.
818 - 826	Shale	Calcareous black shale; core breaks along shear plane in shale; sealed fractures are calcareous.
826 - 827	Limestone	Dense, dark-grey limestone containing aragonitic shell prism fossils of the genus Inoceramus, typical of Cretaceous limestone.
827 - 829	Shale	Black, calcareous shale containing fragments of fossil Inoceramus prisms.
829 - 849	Limestone	Dark-grey, silty to shaly limestone containing fossil fragments; shaly and carbonaceous in lower 1' interval; structurally overturned to the east and dipping 50° W. Limestone weathers light-grey on surface and is light-grey to dark-grey on fresh surface (Timpas ls.).
849 - 851	Limestone	Light to dark-grey, dense limestone (Timpas ls.).
851 - 854	Shale	Very calcareous limy shale; dense core with calcite-filled fractures.
854 - 864	Limestone	Dark-grey to black, dense, fossiliferous limestone; beds overturned to the east and dip 45-55° W.

854 - 864 (cont'd.)		N.B. Several small almost complete Inoceramus shells and crushed Baculite specimens. Dr. Wm. Cobban, U.S.G.S., Federal Center, Denver, corroborates the age establishment of the rocks by the fossils contained in the core.
864 - 873	Shale	Transitional lithologic zone; dark limestones alternate with black calcareous shales.
873 - 884	Limestone	Dark-grey, shaly, fossiliferous limestone zone; fossils are of Timpas limestone equivalents.
884 - 896	Limestone	Shaly, dark-grey to black, dense limestone containing fragments of fossils similar to those described above.
896 - 897	Shale	Calcareous black shale.

........CORING DISCONTINUED AT SLANT HOLE DEPTH OF 897'......

The core samples have been deposited with the Corps of Engineers, Fort Carson, Colorado (27 November 1964) by Steven D. Theodosis.

Bibliography

Berg, R.R., 1960, Cambrian and Ordovician History of Colorado: Guide to the Geology of Colorado, Geol. Soc. Amer. et al, p. 10-17.

Del Rio, S.M., 1960, Mineral Resources of Colorado First Sequel: State of Colorado Mineral Resources Board, 204 State Office Building, Denver 2, Colorado.

Finlay, G.I., 1915, Colorado Springs Quadrangle Folio: U.S. Geological Survey Folio No. 203.

Greene, John, Deep-test Well Data in the Vicinity of Colorado Springs, Colorado: Sample logs made available in 1964 by courtesy of Mr. John Greene, American Stratigraphic Company, 1820 Broadway, Denver 2, Colorado.

Grose, L.T., 1960, Geologic Formations and Structure of Colorado Springs Area, Colorado: Guide to the Geology of Colorado, Geol. Soc. Amer. et al, p. 188-195.

Gross, E.B., 1962, Alkalic Granites and Pegmatites of the Mount Rosa Area, El Paso and Teller Counties, Colorado: University of Michigan Ph.D. Thesis, Plate I, Microfilm Index 63-355.

Harms, J.C., 1959, Structural Geology of the Eastern Flank of the Southern Front Range, Colorado: University of Colorado Ph.D. Thesis.

Hutchinson, R.M., 1960, Structure and Petrology of North End of Pikes Peak Batholith: Guide to the Geology of Colorado: Geol. Soc. Amer. et al, p. 170-180.

Maher, J.C., 1950, Pre-Pennsylvanian Rocks Along the Front Range of Colorado: U.S. Geological Survey Oil and Gas Investigations Preliminary Chart 39.

Ogden, L.T., March 1961, NORAD Excavation Surface Geology: U.S. Corps of Engineers, Omaha District, Omaha, Nebraska.

____________ et al, 1960, NORAD COC Geological Addendum to Definitive Report: U.S. Army Corps of Engineers, Omaha District, Omaha, Nebraska.

Oriel, S.S., and Craig, L.C., 1960, Lower Mesozoic Rocks in Colorado: Guide to the Geology of Colorado, Geol. Soc. Amer. et al, p. 43-58.

Rothrock, D.P., 1960, Devonian and Mississippian Systems in Colorado: Guide to the Geology of Colorado, Geol. Soc. Amer. et al, p. 17-22.

Scott, G.R., 1964, Geology of the Northwest and Northeast Pueblo Quadrangles, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I - 408.

Scott, G.R., and Cobban, W.A., 1964, Stratigraphy of the Niobrara Formation at Pueblo, Colorado: U.S. Geological Survey Professional Paper 454-L, 27 p.

Stose, G.W. et al, 1935, Geologic Map of Colorado: U.S. Geological Survey in cooperation with the Colorado State Geological Survey Board and Colorado Metal Mining Fund.

Theodosis, S.D., 1960, Surface Geologic Maps of a 35-mile Radius of Colorado Springs, Colorado: Geologic map panels of scale 1 in. to 4000 ft., made available by Shell Oil Company.

Vanderwilt, J.W., 1947, Mineral Resources of Colorado: State of Colorado Mineral Resources Board, 204 State Office Building, Denver 2, Colorado.